# The Pursuit of the Impossible

Materials Constraints and Realities for the Net Zero Utopia

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# THE PURSUIT OF THE IMPOSSIBLE



## EXECUTIVE SUMMARY

Many industrialized countries have declared that their policy goal is to phase out the use of fossil fuels (oil, natural gas and coal) and to replace them with all-electric energy systems powered by renewable energy. Adding to the immensity of this challenge, many governments have declared that it must be achieved in almost all countries by 2050, just over 27 years from now. This is the so-called "decarbonization" or "net-zero" goal.

In late 2021, a group led by Simon Michaux of the Geological Survey of Finland produced a 1000-page "Assessment of the Extra Capacity Required of Alternative Energy Electrical Power Systems to Completely Replace Fossil Fuels"[1]. The focus of the study is almost entirely on determining the magnitude of the physical material requirements of decarbonization. Here are some of the findings.

The global fleet of road vehicles in 2019 numbered about 1.416 billion. Of this, only 7.2 million were electric vehicles (EV). Thus, only 0.51% of the road vehicle fleet were EVs and 99.49% of the global fleet was "yet to be replaced".

In 2018, 84.7% of the world's primary energy consumption was met by fossil fuels, whereas renewables (solar, wind, geothermal and biofuels) accounted for only 4.05% and nuclear power 10.1%.

The total additional non-fossil fuel electrical power annual generating capacity that would be needed for complete global decarbonization is around 37,671 terawatt hours (TWh). An additional 221,594 new power plants would have to be constructed and commissioned to meet the power needs of a

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[1] https://tupa.gtk.fi/raportti/arkisto/42_2021.pdf

decarbonized world. To meet the power requirements of complete decarbonization, almost five times as many plants as those now in place today would have to be built, and all this would have to take place in 27 years.



Converting all current (i.e. 1.39 billion) short-range road vehicles to EVs would require the production of an additional 65.19 TWh of batteries (282.6 million tonnes of lithium-ion batteries), and an annual additional 6,158.4 TWh of electricity from the power grid to charge those batteries.

The 282.6 million tonnes of lithium just to power the 1.39 billion short-range road vehicles is beyond current global lithium reserves. Further, each of the 1.39 billion batteries would have a useful working life of only 8 to 10 years, according to International Energy Agency estimates. So, 8-10 years after manufacture, new replacement batteries would be required.

Then there is the issue of battery storage. The battery storage capacity to mitigate intermittent supply on a 24-hour basis would be 2.82 million tonnes. Much more would be needed to protect against seasonal shortfalls. The bulk storage capacity to give the world a four-week buffer (i.e. roughly half of what might be needed in much of the northern hemisphere) would be 573.4 TWh. So, a combined total of 2.78 billion tonnes of lithium would be needed to solve the problem of intermittency. That represents five times global nickel reserves, 11 times 2018 global cobalt reserves and four times global lithium reserves.

One scenario examined the feasibility of replacing all current uses of petroleum product fuels with biomass (i.e. bioethanol and biodiesel). The estimated arable land needed to produce all the biomass required in 2018 would be over 40 million square kilometers. This is more than three and a half times the existing world land use to grow crops. Obviously, there would be no land available to grow food.

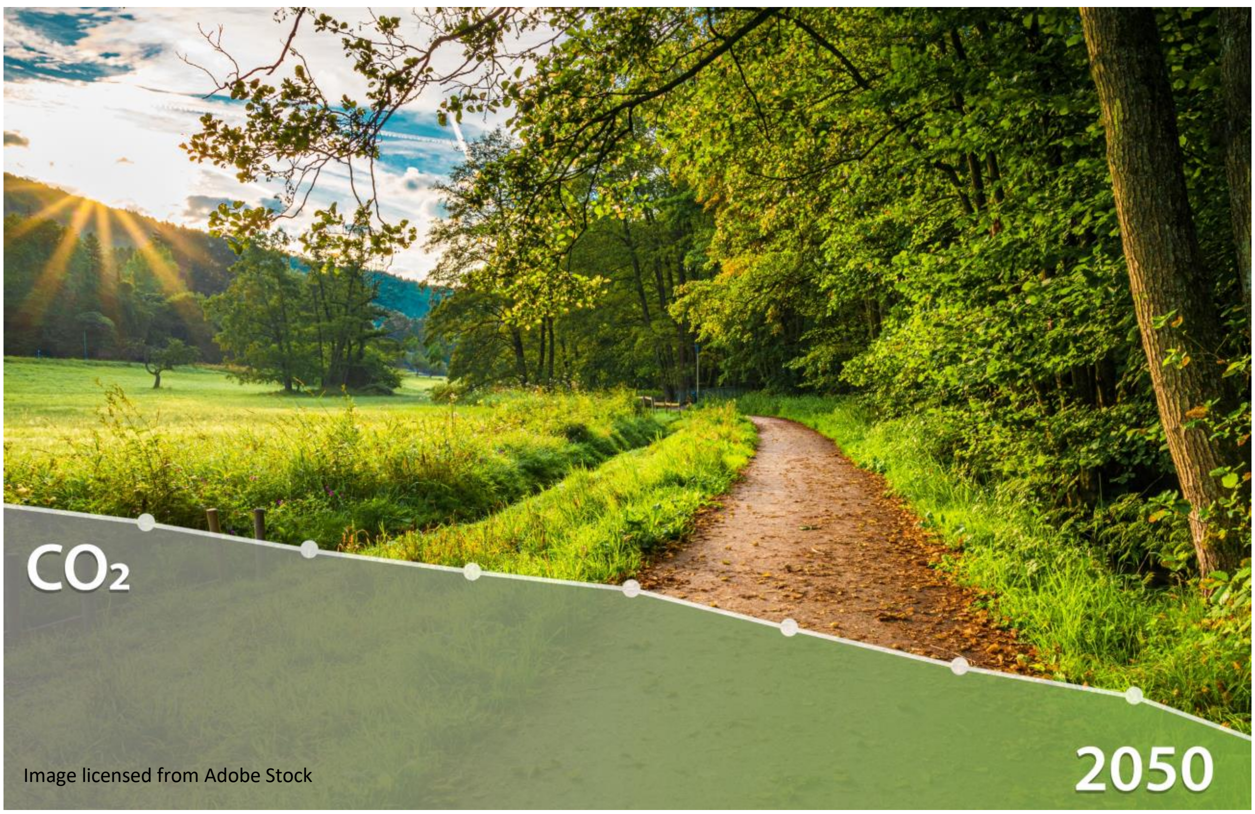
The report adds valuable detail to our understanding of the feasibility of decarbonization within a few decades, although it stops short of acknowledging the obvious – decarbonization by 2050 is flat out impossible. In fact, full global decarbonization's demands on the world's mineral resources may be so immense that it is impossible in any time frame.

# THE PURSUIT OF THE IMPOSSIBLE



## Materials Constraints and Realities for the Net Zero Utopia

Prodded by the United Nations and numerous radical environmentalist organizations, many industrialized countries have declared that their policy goal is to phase out the use of fossil fuels (oil, natural gas and coal) and to replace them with all-electric energy systems powered by renewable energy. Unfortunately, most people in those countries do not understand the magnitude of the physical, economic and social changes that would be entailed in such a transition. Adding to the immensity of this challenge, many governments have declared that it must be achieved in almost all countries by 2050, just over 27 years from now. This is the so-called "decarbonization" or "net-zero" goal.



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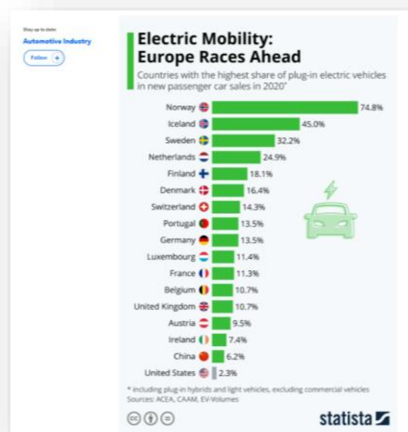
Many prominent experts have attempted to analyze from a macro-economic, or top-down, perspective the costs of attaining the net-zero objective. Until recently, however, none had carried out a bottom-up analysis that sought to model the feasibility of achieving the physical changes required – the production of the minerals, construction of the electrical generation plants, electricity storage facilities, and related transmission and distribution infrastructure. In other words, is net-zero even possible?



In late 2021, a group led by Simon Michaux of the Geological Survey of Finland produced a 1000-page "Assessment of the Extra Capacity Required of Alternative Energy Electrical Power Systems to Completely Replace Fossil Fuels"[2]. The focus of the study is almost entirely on determining the magnitude of the physical material requirements of decarbonization. As data is either poor or unavailable for many regions, the model used calculations based on energy use data in 2018 from only the United States, the European Union and China.

# IMPORTANT FINDINGS

The global fleet of road vehicles in 2019 numbered about 1.416 billion. Of this, only 7.2 million were electric vehicles (EV). Thus, only 0.51% of the road vehicle fleet were EVs and 99.49% of the global fleet was "yet to be replaced". The number of vehicles is far higher than estimated by previous studies. It serves to underline the magnitude of the task of electrifying the world's surface vehicle fleet. **After over 15 years to large subsidies and increasing regulatory requirements seeking to promote EVs, only half of one percent of the world's road vehicles are fully electric.**




In 2018, 84.7% of the world's primary energy consumption was met by fossil fuels, whereas renewables (solar, wind, geothermal and biofuels) accounted for only 4.05% and nuclear power 10.1%.

The total additional non-fossil fuel electrical power annual generating capacity that would be needed for complete global decarbonization is around 37,671 terawatt hours (TWh). **An additional 221,594 new**

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[2] https://tupa.gtk.fi/raportti/arkisto/42_2021.pdf

**power plants would have to be constructed and commissioned to meet the power needs of a decarbonized world. An average of over 8,200 plants per year would have to be built over the next 27 years.** In Europe and North America, it generally takes 12 to 15 years at best to plan, get approval for and build a new powerplant, and 20 to 30 years for nuclear powerplants.


To put this in context, the total global power plant fleet in 2018 was only 46, 423 stations. **To meet the power requirements of complete decarbonization, almost five times as many plants as those now in place would have to be built, and all this would have to take place in 27 years.** Almost 16,000 new plants would be needed in the United States alone.

**Converting all current (i.e. 1.39 billion) short-range road vehicles to EVs would require the production of an additional 65.19 TWh of batteries (282.6 million tonnes of lithium-ion batteries), and an annual additional 6,158.4 TWh of electricity from the power grid to charge those batteries.**

The study assumed that long-distance road transport vehicles, the rail system and marine vessels would be powered by hydrogen fuel cells. *None are so powered today.*

Under a hybrid scenario used to simplify the outcomes, a further 958.6 TWh of non-fossil fuel electrical power would be required to substitute for fossil fuel power generation, heating of buildings and steel manufacture. **The grand total additional non-fossil fuel electrical power annual capacity to be added to the global grid, as noted before, was calculated to be an "astonishing" 37,670.6 TWh.**



**The 282.6 million tonnes of lithium just to power the 1.39 billion short-range road vehicles is beyond current global lithium reserves. Further, each of the 1.39 billion batteries would have a useful working life of only 8 to 10 years, according to International Energy Agency estimates. So, 8-10 years after manufacture, new replacement batteries would be required.** Recycling, when that is possible, will face significant technical, cost and environmental challenges. In theory, there are enough global reserves of nickel to meet vehicle battery requirements, but it would require 48% of 2018 nickel reserves. There is not enough cobalt in current reserves to meet the demand. Further, these estimates ignore the need for lithium, nickel and cobalt to meet other industrial demands for these minerals.


*Mines are typically in remote locations, requiring construction of road/rail infrastructure, power lines, and on-site facilities, all of which entail enormous use of fossil fuels and end up with significant embedded emissions. These factors are not part of the Michaux analysis.*

Then there is the issue of battery storage. Electrical power generated from solar and wind sources are highly intermittent in supply volumes, both across a 24-hour cycle and in a seasonal context (i.e. The peak seasons for solar and wind supply are different from the peak seasons for power demand.) Consequently, a power storage buffer is needed if these generation systems are to be used on a large scale and as a high percentage of total generation capacity. In 2018, pumped storage attached to a hydroelectric power generation system accounted for 98% of global power storage capacity, and there are geographical limitations on how much pumped storage can be added. Decarbonization advocates have endorsed the idea that lithium ion battery banks can be counted on to fill the need for most additional storage.



However, there is an immense problem. The battery storage capacity to mitigate intermittent supply on a 24-hour basis would be 2.82 million tonnes. Much more would be needed to protect against seasonal shortfalls. Until recently, the largest lithium ion battery storage facility in the world was the Hornsdale 100 MW station in Australia, built at a cost of 90 million Australian dollars (Canadian $80 million). The bulk storage capacity to give the world a four-week buffer (i.e. roughly half of what might be needed in much of the northern hemisphere) would be 573.4 TWh. That would require 5.7 million stations the size of Hornsdale, and the mass of lithium ion batteries would be 2.5 billion tonnes. **So, a combined total of 2.78 billion tonnes of lithium would be needed to solve the problem of intermittency. That represents five times global nickel reserves, 11 times 2018 global cobalt reserves and four times global lithium reserves.**


Source: https://hornsdalepowerreserve.com.au/

More insights can be gained concerning the limitations posed by currently available mineral resources by comparing the mass of minerals required to manufacture all the needed lithium-ion batteries to current (i.e. 2018) levels of annual production of those minerals. I have summarized this in Table 1.

**Table 1**

**Years of Production of Key Minerals to Meet One Generation of Vehicle Batteries**

| **Metal** | **Mass Needed (million Tonnes)** | **Years Required** |
|---|---|---|
| **Copper** | 48.0 | 2.3 |
| **Aluminum** | 24.0 | 0.4 |
| **Nickel** | 42.9 | 18.7 |
| **Cobalt** | 7.9 | 56.3 |
| **Lithium** | 6.1 | 72.1 |
| **Graphite** | 62.2 | 66.8 |

*Source: Geological Survey of Finland*

Table 1 indicates that, especially in the cases of nickel, cobalt, lithium and graphite, the years of current global production far exceed what would be needed to produce one generation of batteries for an entirely electrified global surface vehicle fleet.

**Table 2 – Screenshot from Michaux' Video Presentation**

| Metal | Element | Total metal required produce one generation of technology units to phase out fossil fuels (tonnes) | Global Metal Production 2019 (tonnes) | Years to produce metal at 2019 rates of production (years) |
|---|---|---|---|---|
| Copper | Cu | 4 575 523 674 | 24 200 000 | 189,1 |
| Nickel | Ni | 940 578 114 | 2 350 142 | 400,2 |
| Lithium | Li | 944 150 293 | 95 170 * | 9920,7 |
| Cobalt | Co | 218 396 990 | 126 019 | 1733,0 |
| Graphite (natural flake) | C | 8 973 640 257 | 1 156 300 ♦ | 3287,9 |
| Graphite (synthetic) | C | | 1 573 000 ♦ | - |
| Silicon (Metallurgical) | Si | 49 571 460 | 8 410 000 | 5,9 |
| Vanadium | V | 681 865 986 | 96 021 * | 7101,2 |
| Rare Earth Metals | - | | | |
| Neodymium | Nd | 965 183 | 23 900 | 40,4 |
| Germanium | Ge | 4 163 162 | 143 | 29113,0 |
| Lanthanum | La | 5 970 738 | 35 800 | 166,8 |
| Praseodymium | Pr | 235 387 | 7 500 | 31,4 |
| Dysprosium | Dy | 196 207 | 1 000 | 196,2 |
| Terbium | Tb | 16 771 | 280 | 59,9 |

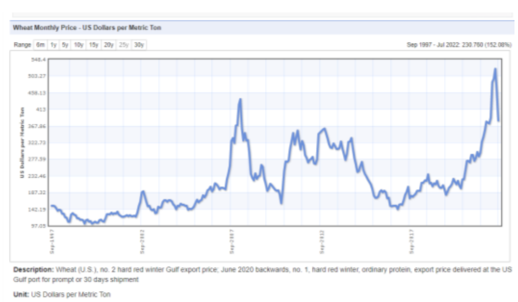
*Extrapolating the data to phase out fossil fuels for the new economy.*
*Michaux's study models the viability for the three significant global players –*
*China, the USA and Europe (EU28).* https://youtu.be/MBVmnKuBocc [3]

[3] Knowledge around known mineral resources suggests the raw materials required for the manufacture and servicing of these renewable technologies will remain truly global in nature. There will not be one nation or geographic region that can be truly self-sufficient. The focus of this report therefore was to model the viability of the new global ecosystem using calculations made specifically for the three significant global players: the United States (US) economy; the European (EU-28) economy; and the Chinese economy.

How long would it take to radically increase production? The process of exploring for and developing new mineral resources does not follow any fixed or predictable schedule. Once the resources are found, more time would be needed to build mines and expand the capacity of existing mines where that is possible. Typically in North America, moving from mineral discovery to first mine production takes at least 15 years, but it can take much longer if opposition by environmentalist, indigenous and other organizations is delayed by the courts of political decisions. These considerations alone throw into doubt the credibility of current "net-zero" timetables.

One scenario examined the feasibility of replacing all current uses of petroleum product fuels with biomass (i.e. bioethanol and biodiesel). This is sometime touted as a way to sharply reduce greenhouse gas emissions from aviation, as the weight and size of batteries makes electrification of commercial aircraft unfeasible. **The estimated arable land needed to produce all the biomass required in 2018 would be over 40 million square kilometers. This is more than three and a half times the existing world land use to grow crops.** The additional land required, were it possible to convert it to crop growth, would result in the near complete deforestation of the remaining forests on Earth. Obviously, there would be no land available to grow food. Simply replacing global gasoline supplies with biomass fuels would require 16 million square kilometers of land. That is ten times the amount of arable land in the United States. Replacing just current jet fuel use with biofuels would require 831,000 square kilometers of land, or about twice the amount of arable land in Canada.

Advocates of decarbonization pay relatively little, if any, attention to the implications of phasing out petrochemical fertilizers, herbicides and pesticides. About 9% of global natural gas demand is used to produce ammonia for the industrial manufacture of fertilizer, which in turn is critical for global food production. The authors of the Geological Survey of Finland report state that they were *"unable to cite any viable substitute for the use of natural gas in the production of petrochemical fertilizers".* They blithely recommend the use of organic farming. However, without modern fertilizers, decarbonization would cut food production by more than 50%, and billions of people would starve.




Cost of fertilizer due to rise in natural gas prices/closure of fertilizer factories, plus, loss of agriculture land/shipments due to Ukraine-Russia conflict drive up wheat prices. *Image licensed from Adobe Stock.*

The Final Summary of the report includes the following statements:

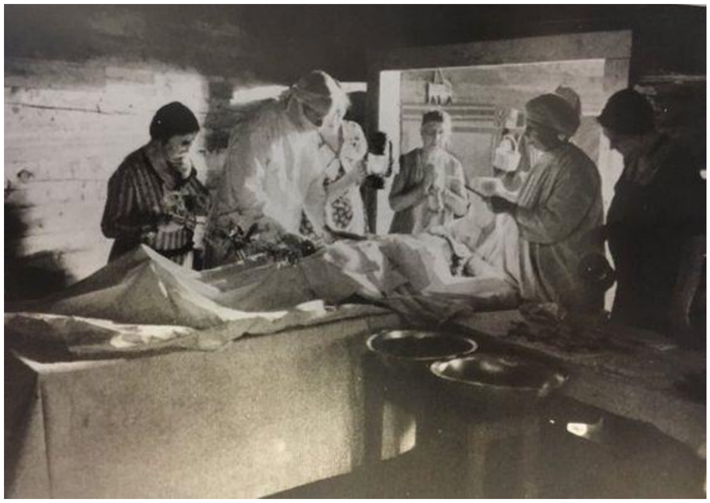


*"A fundamental conclusion is that replacing the existing fossil fuel powered system (oil, gas and coal) using renewable technologies, such as solar panels or wind turbines, will not be possible for the global human population in just a few decades. There is just not the time nor the resources to do this. What may well happen is a significant reduction of societal demand of all resources of all kinds. This implies a very different social contract and a very different system of governance to what is in place today."*

# COMMENT

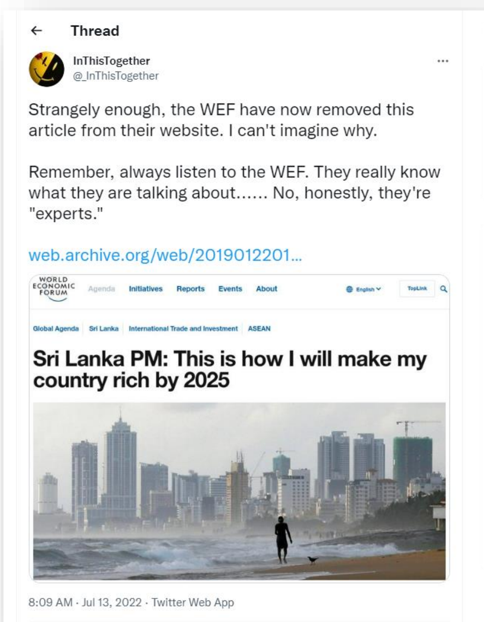
This report contains a treasure trove of factual information about the physical requirements to produce energy supplies and the implications of seeking to change the current global energy system. The numbers are a bit overwhelming, and often so large as to be incomprehensible to the average person. **The report also adds valuable detail to our understanding of the feasibility of decarbonization within a few decades, although it stops short of acknowledging the obvious – decarbonization by 2050 is flat out impossible.** In fact, full global decarbonization's demands on the world's mineral resources may be so immense that it is impossible in any time frame.

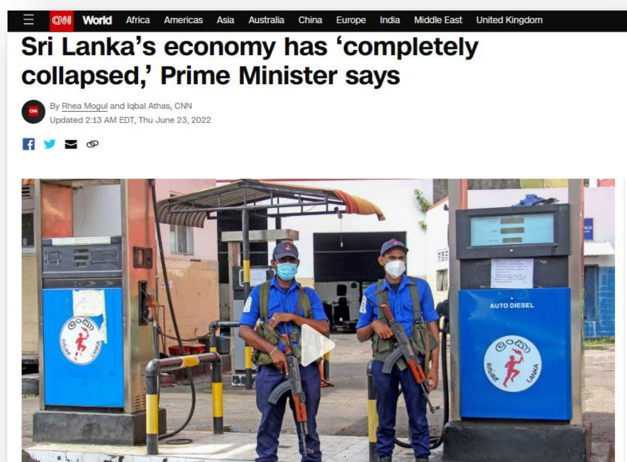

The bottom-up approach used in the report, while offering important insights, also leaves out much that is gained from top-down studies. For example, the absence of any commentary on the economic and political limitations that affect decarbonization is a major flaw in the report. Important questions abound. Can one really ignore the effect of governments' attempting to deprive consumers of reliable and affordable energy sources? Would the public in democratically-governed countries support a transition to a centrally-planned and extraordinarily intrusive political system? In principle, how can one justify a policy that imposes enormous costs, offers no "climate" benefits and depletes the earth's mineral resources at rates beyond imagining? Who would bear the costs – the costs of forcing the use of uneconomic energy sources, the loss of income to countries that produce fossil fuels, the effects of resource depletion, the loss of access to aviation for passenger and freight transport, and so on and so on? Why should we accept that billions must starve to "save the planet"?



*NetZero medical care. A return to kitchen table surgery.*

The study's limp conclusion that we need "a different social contract and system of governance than what is in place today" is a thinly veiled endorsement of the anti-growth totalitarian-inspired manifesto that we have heard from both useful idiots like Greta Thunberg and the more sophisticated and powerful representatives of the World Economic Forum. Even when they are documenting the practical impossibility of "net-zero", decarbonization advocates embrace the horror of its likely consequences.




https://www.cnn.com/2022/06/23/asia/sri-lanka-economy-collapse-prime-minister-intl-hnk/index.html

## ABOUT THE AUTHOR

Robert Lyman is an economist with 27 years' experience as an analyst, policy advisor and manager in the Canadian federal government, primarily in the areas of energy, transportation, and environmental policy. He was also a diplomat for 10 years. Subsequently he has worked as a private consultant conducting policy research and analysis on energy and transportation issues as a principal for Entrans Policy Research Group. He is a frequent contributor of articles and reports for Friends of Science, a Calgary-based independent organization concerned about climate change-related issues. He resides in Ottawa, Canada. Full bio.

## ABOUT FRIENDS OF SCIENCE SOCIETY

Friends of Science Society is an independent group of earth, atmospheric and solar scientists, engineers, and citizens that is celebrating its 20th year of offering climate science insights. After a thorough review of a broad spectrum of literature on climate change, Friends of Science Society has concluded that the sun is the main driver of climate change, not carbon dioxide ($CO_2$).

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